



## NASA STTR 2022 Phase I Solicitation

### T14.01 Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

Lead Center: GRC

Participating Center(s): JSC

#### Scope Title

Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

#### Scope Description

This subtopic seeks technologies related to cryogenic propellant (e.g., hydrogen, oxygen, and methane) production, storage, transfer, and usage to support NASA's in situ resource utilization (ISRU) goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions to the Moon and Mars. Anticipated outcomes of Phase I proposals are expected to deliver proof of the proposed concept with some sort of basic testing or physical demonstration. Proposals shall include plans for a prototype and demonstration in a defined relevant environment (with relevant fluids) at the conclusion of Phase II. Solicited topics are as follows:

- Develop an in situ hydrogen safety sensor to detect concentrations of hydrogen gas within high-pressure oxygen systems. Regenerative fuel cells (RFCs) and ISRU systems use water electrolysis to generate hydrogen and oxygen for either propellants or energy storage. For safety reasons, there is a need to monitor the quantity of hydrogen within saturated (noncondensing) oxygen process streams flowing up to 50 SLPM to ensure product gas purity. This is especially true for high-pressure systems that range from 250 to 2500 psia. Current technologies require the use of a slipstream to condition the sample gases for analysis. This slipstream represents a loss of reactants and imposes both power and mass penalties on systems deployed on the lunar surface. Existing sensor calibration intervals currently do not support the identified NASA maintenance intervals defined by lunar surface access by crewed missions (>30,000 hr, targeting >50,000 hr). As this application is critically limited by available power and mass, preference is given to solutions with lower parasitic power and mass as well as systems without a slipstream to lose reactants.
- Develop and implement computational methodology to enhance the evaluation of temperature and species gradients at the liquid/vapor interface in unsettled conditions. Techniques could include arbitrary Lagrangian-Eulerian (ALE) interface tracking methods with adaptive mesh morphing, interface reconstruction methods, immersed boundary approaches, or enhanced-capability level set and volume of fluid (VOF) scheme that decrease numerically generated spurious velocities and increase gradient evaluation accuracy. The uncertainty of such techniques in determining the interfacial gradients should be <5% and on par with accuracies of a sharp interface method applied to a nonmoving, rigid interface. Applications include cryogenic tank self-pressurization, pressure control via jet mixing, and filling and liquid transfer operations. It is highly desirable if the methodology can be implemented via user-defined functions/subroutines into commercial computational fluid dynamics (CFD) codes. The final deliverable should be the documentation

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showing the detailed formulation, implementation, and validation, and any stand-alone code or customized user-defined functions that have been developed for implementation into commercial codes.

### **Expected TRL or TRL Range at completion of the Project**

2 to 4

### **Primary Technology Taxonomy**

#### **Level 1**

TX 14 Thermal Management Systems

#### **Level 2**

TX 14.1 Cryogenic Systems

### **Desired Deliverables of Phase I and Phase II**

- Hardware
- Software
- Prototype

### **Desired Deliverables Description**

Phase I proposals should at a minimum deliver proof of the concept, including some sort of testing or physical demonstration, not just a paper study. Phase II proposals should provide component validation in a laboratory environment preferably with hardware (or model subroutines) deliverable to NASA.

Deliverables for the hydrogen sensing technologies for oxygen streams would be at least two operational sensor package test articles demonstrating the capability of the sensor to be tested at a NASA center in either a RFC system or an ISRU. These sensors must have a detection range of at least 0% to 4% hydrogen in oxygen with a minimum detection limit of 20 ppm. The process fluid temperatures will range from -40°C to 110°C due to environmental temperatures on the lunar surface. The Phase I prototypes must demonstrate operation at pressures greater than or equal to 250 psia while Phase II prototypes must demonstrate operation at pressures greater than or equal to 2,500 psia.

Deliverables for the modeling: Phase I should demonstrate the accuracy of the method for simulating self-pressurization under unsettled, low-gravity conditions. Phase II should demonstrate the accuracy of the method for simulating jet mixing and filling and transfer operations. The final deliverable should be the documentation showing the detailed formulation, implementation, and validation, and any stand-alone code or customized user-defined functions that have been developed for implementation into commercial codes.

### **State of the Art and Critical Gaps**

Cryogenic Fluid Management (CFM) is a cross-cutting technology suite that supports multiple forms of propulsion systems (nuclear and chemical), including storage, transfer, and gauging, as well as liquefaction of ISRU-produced propellants. The Space Technology Mission Directorate (STMD) has identified that CFM technologies are vital to NASA's exploration plans for multiple architectures, whether it is hydrogen/oxygen or methane/oxygen systems including chemical propulsion and nuclear thermal propulsion.

Current hydrogen sensing technologies have three key features inhibiting their use in NASA applications: low pressure capability, unacceptably low calibration stability, and a required slipstream to condition the sample gases for analysis. The low pressure prevents monitoring hydrogen in ISRU propellant streams or RFC energy storage systems. This slipstream represents a loss of reactants and imposes both power and mass penalties on systems deployed on the lunar surface. Based on the performance of hydrogen sensors used in the low-pressure International Space Station (ISS) Oxygen Generator Assembly (OGA) and in terrestrial hydrogen depots, existing sensor calibration intervals currently do not support the identified NASA maintenance intervals defined by lunar

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surface access by crewed missions.

## Relevance / Science Traceability

STMD strives to provide the technologies that are needed to enable exploration of the solar system, both manned and unmanned systems, and CFM is a key technology to enable exploration. Whether liquid oxygen/liquid hydrogen or liquid oxygen/liquid methane is chosen by Human Exploration and Operations Mission Directorate (HEOMD) as the main in-space propulsion element to transport humans, CFM will be required to store propellant for up to 5 years in various orbital environments. Transfer will also be required, whether to engines or other tanks (e.g., depot/aggregation), to enable the use of cryogenic propellants that have been stored. In conjunction with ISRU, cryogenics will have to be produced, liquefied, and stored, the latter two of which are CFM functions for the surface of the Moon or Mars. ISRU and CFM liquefaction drastically reduces the amount of mass that has to be landed on the Moon or Mars.

Generating hydrogen from water electrolysis includes an extremely small but nonzero potential for hydrogen to contaminate the oxygen stream. Monitoring this process for medium pressure systems (e.g., ISRU) or high pressure systems (e.g., energy storage) adds another layer of protection for sustained operation on the surface of the Moon or Mars.

## References

1. Kartuzova, O., and Kassemi, M., "Modeling K-Site LH2 Tank Chillo down and no Vent Fill in Normal Gravity," AIAA-2017-4662.
2. Regenerative Fuel Cell Power Systems for Lunar and Martian Surface Exploration, <https://arc.aiaa.org/doi/abs/10.2514/6.2017-5368> (link is external).
3. NASA Technology Roadmap, <https://gameon.nasa.gov/about/space-technology-roadmap/>, §TA03.2.2.1.2. Chemical Power Generation and §TA03.2.2.2.3. Regenerative Fuel Cell Energy Storage (NOTE: This may be a dated link as this Roadmap still references ETDP/ETDD.).
4. Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production, <https://doi.org/10.1016/j.reach.2019.100026> (link is external).

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